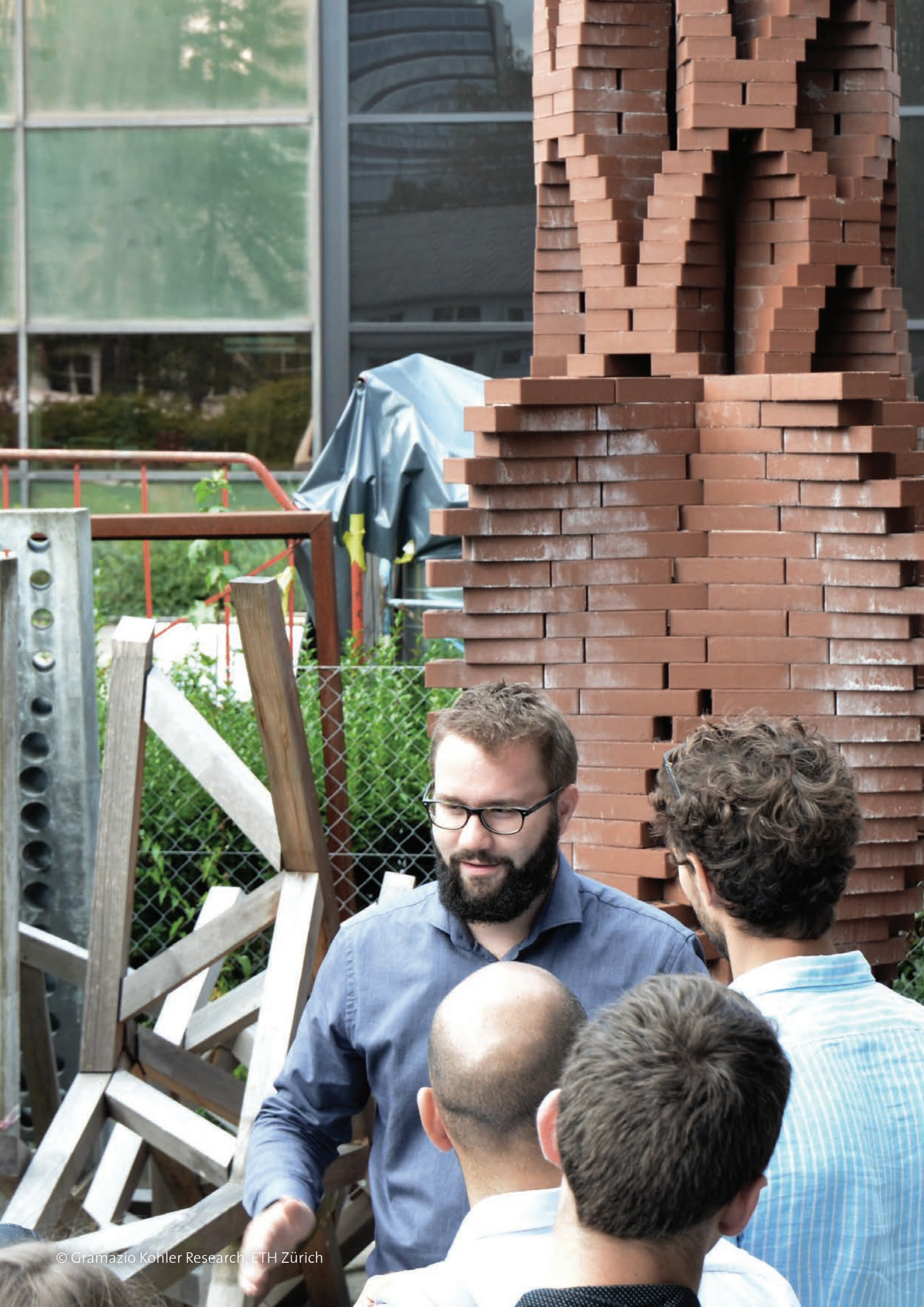
LUKA PISKOREC, MSc ETH Arch
2016



SURNAME	**PISKOREC**
NAME	**LUKA**
TITLE	MSc ETH Arch
PERSONAL ADDRESS	Schützenrain 31 8047 Zürich, Switzerland
ACADEMIC ADDRESS	Gramazio Kohler Research Stefano-Franscini-Platz 1 8093 Zürich, Switzerland
OFFICE ADDRESS	TEN Kanzleistrasse 80 8004 Zurich, Switzerland
TEL	**+41 79 362 1102**
E-MAIL	**piskorec@arch.ethz.ch** lukapiskorec@gmail.com
WEB	**www.lukapiskorec.com**
DATE OF BIRTH	27.08.1986
PLACE OF BIRTH	Bjelovar, Croatia
NATIONALITY	Croatian
LANGUAGES	Croatian (native) English (fluent) German (fluent)

SHORT BIO

LUKA PISKOREC studied architecture at the University of Zagreb in Croatia and worked in architectural offices in Croatia and Switzerland. He continued his studies at the ETH in Zürich and received his Master of Science in Architecture (MSc ETH Arch) in 2011. During his studies, he concentrated on digital fabrication techniques as well as algorithmic programming procedures applied to architecture. He organized and led multiple international workshops on the related topics. Since 2011, he is working as a research assistant at Gramazio Kohler Research at ETH Zürich. From 2011 to 2014, he was leading the Chair's elective course and elective thesis workshops dealing with the development of robotic digital fabrication techniques and their implementation in architectural design. From January 2015 he is involved in teaching at the newly formed Master of Advanced Studies (MAS) in Digital Fabrication, which is initiated by NCCR DFAB and conducted at ETH Zürich. In 2015 he co-founded the Zürich based TEN Association, a group dedicated to initiation and promotion of cultural ventures.

BUILT

PROGRAMMED COLUMN

Robotic fabrication has the potential to rethink even the oldest building module in the world. It enables us something not possible anymore under the modern economic paradigm: precise and highly differentiated placement of every module in the structure.

TYPE	Column, additive robotic assembly
MODE	Student project done at Gramazio Kohler Research, ETH Zürich
STATUS	Built
YEAR	2010
PLACE	ETH, Zürich, Switzerland
SIZE	0.5 m x 0.5 m x 4 m
MATERIALS	Standard bricks connected with construction glue
SOFTWARE	Maya, Python
SETUP	Kuka KR 150 L110 on linear track
ROLE	Student
COLLABORATORS	Michael Knauß (project lead), Ralph Bärtschi, Jennifer Furstenau, Lorenz Lachauer, Mike Lyrenmann
STUDENTS	Sebastian Cramer, Jari Fischer, Benjamin Heller, Pierre Levy, Claudio Meletta, Stephanie Monney, Florian Strohmaier, Thomas Summermatter, Rainer Vock
SPONSORS	Keller Ag Ziegeleien

DESCRIPTION

Additive processes, the ones where we don't throw any or little material away, become one of our most powerful tools in an attempt to transform our building processes from waste-creating to waste-using. Brick, as one of the most ancient building materials, as well as one that can be recycled, became our material of choice to investigate the potential of building in height with robotic resources. The goal here was not automation, but potential for mass customization. Precision, not speed, could enable us to translate our designs into the physical world that were before impossible, or in the best case, that required artisans rather than construction workers. Starting from a simple shape transformation rules on a circle based on an iterative algorithm, building layer by layer, we were able to achieve a variety of spatial effects with just three parameters. Tests with physical models as well as computer simulations enabled us to narrow our design space and to pick the production piece. Based on the findings of the elective course The Programmed Column, the students were challenged to design and fabricate three prototypical brick columns of 4 m height each within a four-week workshop. Functional load bearing criteria had to be integrated with the column design in a parametric system. By the means of models, prototypes in 1:1 scale and digital simulations within a software package for structural analysis the students designed three different prototypes that were subsequently assembled on a robotic fabrication unit. The course was conducted in collaboration with BLOCK Research Group - Chair of Building Structure, prof. Philippe Block.

PROCEDURAL WALL

Sand casting is a manufacturing method several millennia old which could today provide a sustainable alternative for non-standard concrete molds. Its availability and easiness to process lends itself well to the highly controlled robotic manufacturing processes.

TYPE	Wall panel, additive robotic aggregation and concrete casting
MODE	Student project done at Gramazio Kohler Research, ETH Zürich
STATUS	Built
YEAR	2011
PLACE	ETH, Zürich, Switzerland
SIZE	2 m x 1 m
MATERIALS	Reinforced concrete casted on the latex coated sand formwork
SOFTWARE	Rhino, Python
SETUP	Universal Robots UR5, Kuka KR 150 L110 on linear track
ROLE	Student
COLLABORATORS	Michael Knauß (project lead), Axel Vansteenkiste, Prof. Girot, ILA und Yael Girot, Atelier Girot, Prof. Dr. Robert Flatt, Heinz Richner (IfB ETHZ)
STUDENTS INSTALLATION	Tobias Abegg, Mihir Bedekar, Daria Blaschkiewitz, Hernan Garcia, Jitesh Mewada, Ho Kan Wong
SPONSORS	Sika AG

DESCRIPTION

Using a simple sand additive process on a straight, parallel paths, with a fixed pouring height and varying speeds, we were able to achieve a whole spectrum of spatial inter-relationships on the surface of the sand. These were sprayed with latex to achieve surface rigidity and then used as a mold for concrete. Hills and valleys now become ribs whose exact dimensions and spatial placement is governed by strict structural and functional requirements for a retaining wall, conceptually a part of public Rhine river promenade in Basel. Changing soil configuration, ground water level as well as varying tieback height produces different material placement in the wall and therefore different structural reading. The wall becomes a window to the landscape behind.

FRAGILE STRUCTURE

Traditional brick module is defined not only through its size but also through its final position in the architectural element. By placing it on its less stable side, the modules have to start cross-linking to retain stability and the architectural element itself has to be rethought.

TYPE	Wall, in situ robotic assembly
MODE	Research and teaching project done at Gramazio Kohler Research, ETH Zürich
STATUS	Built
YEAR	2012
PLACE	ETH, Zürich, Switzerland
SIZE	8 m x 2.5 m
MATERIALS	Dry stacked wood boards
SOFTWARE	Rhino, Python, Robot Studio
SETUP	ABB IRB 4600 on mobile platform for the final installation, Universal Robots UR5 for the prototyping phase
ROLE	Teaching lead
COLLABORATORS	Volker Helm, Selen Ercan, Thomas Cadalbert, Michael Knauss, Dominik Weber, Ralph Bärtschi
STUDENTS INSTALLATION	Petrus Aejmelaeus-Lindström, Leyla Ilman, David Jenny, Michi Keller, Beat Lüdi
STUDENTS PROTOTYPING	Petrus Aejmelaeus-Lindström, Koray Akdag, Susanne Büchi, Pascal Genhart, Patrick Goldener, Benedikt Hengartner, David Jenny, Sylvius Kramer, Beat Lüdi, Dorian McCarthy, Mario Sgier, Fabio Stirnimann, Florence Thonney, Yifei Wang, Tobias Wullschleger
SPONSORS	Schilliger Holz AG

DESCRIPTION

During the semester the students examined the inherent stabilities of robotic construction processes. Evaluating additive assemblies of discrete elements allowed them to not only draw conclusions on the resulting overall stability but also to consider the assembly equilibrium at each fabrication step. In this way, novel structural and spatial aggregations are designed and fabricated where to a certain extent their materialization is deliberately manipulated and improved through iterative “evolution”. The prototypes in model scale were developed in teams using small six-axial robots and custom-built tools. To deepen the knowledge gained in the elective course the students examined the potential of a robot-based assembly of discrete wood elements in an architectural scale. For this purpose it was essential to enhance robotic operational capabilities from traditional industrial environments (limited to constant conditions) to the production of complex architectural components on site. The aim was to adapt the precision and speed of the robot to the complexity of real building conditions and to combine this with cognitive characteristics of the user. Here, the parking garage of the Department of Architecture at ETH Zürich proved as a suitable place where the character of a research laboratory could effectively be linked with that of a real construction site. As a consequence a complex wooden structure could be assembled with a mobile robot unit. The scale and modularity of the structure were directly derived from the surrounding spatial conditions. In fact, the geometrically differentiated assembly is based on the inherent stability of the overall structure, which consists of more than a thousand individually positioned wood members and is assembled without additional fasteners. From this, it is derived not only specific design and structural aspects, but also it is made possible a new form of articulation in digital fabrication processes in architecture.

© Gramazio Kohler Research, ETH Zürich

SPATIAL AGGREGATIONS

There are many reasons to argue for spatial complexity in architectural structures, adding structural height with efficient material use being one of them. But handling this complexity requires advanced design methods and highly controllable fabrication processes.

TYPE	Pavilion, robotic pre-fabrication with manual assembly
MODE	Research and teaching project done at Gramazio Kohler Research, ETH Zürich
STATUS	Built
YEAR	2012
PLACE	ETH, Zürich, Switzerland
SIZE	6 m x 6 m x 2.5 m
MATERIALS	PVC pipes connected with cable ties
SOFTWARE	Rhino, Python
SETUP	Kuka KR 150 L110 on linear track, Universal Robots UR5 for the prototyping phase
ROLE	Project lead
COLLABORATORS	Ralph Bärtschi, Thomas Cadalbert, Ena Lloret
STUDENTS INSTALLATION	Stella Azariadi, Sonja Cheng, Ivana Damjanovic, David Jenny, Andreas Kissel, Jennifer Koschack, Bo Li, Joe Liao, Lukas Mersch, Evangelos Pantazis, Stylianos Psaltis, Gabriela Schär, Katharina Schwiete, Enzo Valerio, James Yeo, Sasada Yushi
STUDENTS PROTOTYPING	Petrus Aejmelaeus-Lindström, Stella Azariadi, Ripple Chauhan, Sonja Cheng, Ivana Damjanovic, Christian Grewe Rellmann, David Jenny, Eveline Job, Andreas Kissel, Bo Li, Joe Liao, Lukas Mersch, Evangelos Pantazis, Kulshresth Patel, Stylianos Psaltis, Tarika Sajnani, Gabriela Schär, Hjalmar Schmid, Katharina Schwiete, Rahil Shah, Josiena Simonian, Enzo Valerio, Janki Vyas, James Yeo, Sasada Yushi
SPONSORS	REHAU Vertriebs AG

DESCRIPTION

The course dealt with spatial assemblies created through positioning of straight rod-like elements in space by making use of robot`s six degrees of freedom and man-to-machine interaction. It was investigated into buildup sequences as well as into evaluation logics that allow to aggregate spatial structures without the need of additional scaffolding. Such aggregations lead away from conventional space-frame typologies, performing ever more complex structural capabilities. Through developing different man-to-machine buildup procedures, optimal work-flow can be achieved without compromising the design's intricacy. In this, a new digital design and fabrication scope is enabled while generating robust, inherently redundant aggregations with multiple load paths and connection opportunities. During the elective thesis the students continued to examine robotic construction processes using straight rod-like elements and man-to-machine interaction. Multiple designs from the elective course were evaluated and developed further, ranging from programming to 1:1 prototype testing. This included a constructive assembly system with optimized joining and build-up sequencing. Consequently, this custom prefabrication setup was used to design and build a 6 m x 6 m pavilion, made from 700 meters of PVC pipes (32 mm diameter) in the Chair's robotic facility. In this, the pavilion's assembly sequence exerted a decisive influence on the architectural design and building process. Essential here is both the spatial accessibility and the structural stiffness generated by the connection of the individual elements. On that scope, the pavilion formed a coherent, differentiated and nevertheless harmonious whole, representing a unique and highly resolved spatial structures that demonstrates the potential for future adaptive and recursive processes in digital design and construction.

SHIFTED FRAMES

The simple-most way to connect rectangular wooden timber elements is with a side-to-side connections and keeping them either orthogonal or parallel to each other. It is remarkable how much variety can be produced from these simple rules.

TYPE	Pavilion, additive robotic assembly
MODE	Research and teaching project done at Gramazio Kohler Research, ETH Zürich
STATUS	Built
YEAR	2013
PLACE	ETH, Zürich, Switzerland
SIZE	6 m x 6 m x 4.5 m
MATERIALS	Wood beams connected with screws
SOFTWARE	Rhino, Python, Robot Studio
SETUP	ABB IRB 4600 on mobile platform, Universal Robots UR5 for the prototyping
ROLE	Project lead
COLLABORATORS	Selen Ercan (fabrication lead)
STUDENTS INSTALLATION	Carlos Cenci, Guilherme Da Silva Carvalho, Luis Gisler, Andreas Kissel, Isabelle Nützi, Stefan Roos
STUDENTS PROTOTYPING	Marisa Brunner, Carlos Cenci, Tino Crameri, Guilherme Da Silva Carvalho, Bettina Dobler, Nicolas Ganz, Melchior Hösli, Bo Li, Leonardo Magursi, Isabelle Nützi, Haitao Pang, Robby Rey, Stefan Roos, Chang Su , Ying Yi Tan, Akihiko Tanigaito, James Yeo, Jason Yeung

DESCRIPTION

In this semester the students continued to explore complex spatial aggregations and concentrated especially on robotic assembly of straight beam elements. These were assembled in orthogonal relation, using simple side-to-side connections without any extra joints. Although composed out of generic elements, the system has a capacity to build a wide range of complex configurations. Due to the additive assembly of multiple beam elements, differentiated and highly redundant structural systems were created that allowed specific investigations of new design and construction methods for complex truss structures. The students tested their design, structural and procedural constructive logics directly on robotic fabrication of model scale prototypes. For the elective thesis course Shifted Frames, a design from the previous semester course was elaborated and fabricated at full scale on the ETH Hönggerberg campus. The pavilion consisted of 252 interwoven wooden frames of different sizes that were locked in place by screws. Designed as an orthogonal aggregation of over 1,500 wood beams that fill out the complete volume of the pavilion, varying densities modulate the view through as well as from inside the structure. It was fabricated in 18 parts at the Chair's robotic facility before it was put together on site. The robot arm performed the cutting of each individual element as well as demanding spatial positioning inside every pavilion part, while fixing of the beams was done in a man-machine procedure. In this way Shifted Frames explores not only highly informed and robotically aggregated spatial structures but also fosters innovative human-machine collaboration at full architectural scale.

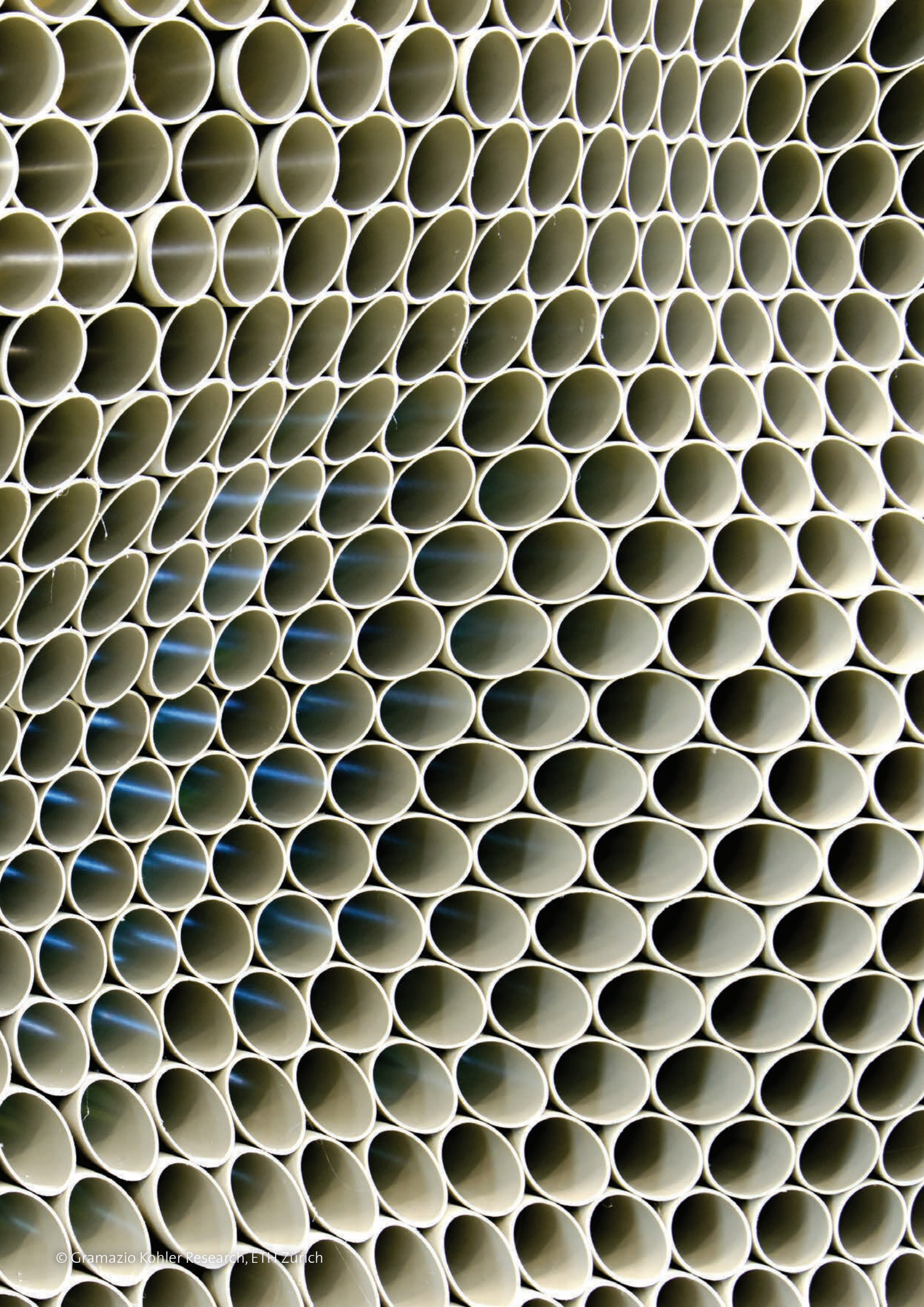
COMPLEX TIMBER STRUCTURES

Most of the complexity of a spatially complex timber structure is contained within the joint between the elements. This complexity can be encoded spatially through precise cuts and placements, while the joining technique itself can be simple.

TYPE	Funnel structure, robotic process with integrated pre-fabrication and complex spatial assembly
MODE	Research and teaching project done at Gramazio Kohler Research, ETH Zürich
STATUS	Built
YEAR	2013
PLACE	ETH, Zürich, Switzerland
SIZE	1.8 m – 5 m x 3 m
MATERIALS	Wood beams connected with screws
SOFTWARE	Rhino, Python, Grasshopper, Robot Studio
SETUP	ABB IRB 4600 on mobile platform with auxiliary rotating platform, Universal Robots UR5 for the prototyping
ROLE	Teaching lead
COLLABORATORS	Michael Knauss
STUDENTS INSTALLATION	Marisa Brunner, Christian Grewe Rellmann, Rossitza Kotelova, Enrique Ruiz Durazo, Andreas Thoma
STUDENTS PROTOTYPING	Lukas Ballo, Nishtha Banker, Tom Doan, Jacob Fink, Dominik Ganghofer, Pierre-Jean Holl, Rossitza Kotelova, Renuka Makwana, Daniel Michel, Unnati Mistry, Takashi Owadat, Irene Prieler, Micha Ringger, Pascal Ruckstuhl, Enrique Ruiz Durazo, Mari Saetre, Grau Sara, David Schildberger, Nishita Shah, Abigail Stoner, Taku Sugimoto, Andreas Thoma, Achilleas Xydis

DESCRIPTION

The elective course Complex Timber Structures dealt with the design and fabrication of spatial structures of beam shaped wooden elements. The students analyzed traditional and contemporary timber systems and reinterpreted those using digital tools. The digital fabrication technology and the resulting opportunities and constraints formed the basis for the design of the students. The students built their designs on a model scale with small robots using specially developed programming tools. Integration of the robot-building process constraints such as length, angle constraints of the components and the assembly sequence of the structures defined in a significant manner the specific student design solutions. Following an elective course, a four-week workshop Complex Timber Structures offered the students an opportunity to deepen the themes from the semester. The students began with an analysis of contemporary and traditional timber systems and defined node typologies suitable for the digital fabrication process. They followed by designing, programming and building a funnel-shaped wooden structure with a span of 4.5m consisting out of 93 individually cut wooden beams. The cutting of the beams, drilling the holes for the screws and the precise placement of the components within the structure was carried out in a continuous robot-based process. The constraints given by the robot-fabrication process such as length, angle constraints of the components and the assembly sequence of the structure were already incorporated in the planning phase of the design process and have been an integral part of the architectural design. The teaching project was conducted as an integral part of the 3-year NFP66 research project Additive Fabrication of Complex Robotic Timber Structures.



DEPTH MODULATIONS

Today's industry provides many ways of producing highly complex but mass-produced building modules. With precise control, the differentiation potential of such pieces can be utilized in the production of highly articulated architectural elements.

TYPE	Three wall panels, robotic process with integrated pre-fabrication and additive assembly
MODE	Research and teaching project done at Gramazio Kohler Research, ETH Zürich
STATUS	Built
YEAR	2014
PLACE	ETH, Zürich, Switzerland
SIZE	2.5 m x 1.4 m
MATERIALS	PVC tubes with acryl inserts, connected together with hot melt adhesive
SOFTWARE	Rhino, Python, Grasshopper
SETUP	Kuka KR 150 L110 on linear track, Universal Robots UR5 for the prototyping
ROLE	Teaching lead
COLLABORATORS	Max Vomhof, Lauren Vasey (fabrication lead)
STUDENTS INSTALLATION	Pierre Chevremont, Maged Elsadek, Andreas Häni, Mathias Gfeller, Clemens Klein, Romain Kündig, Thierry Raess, Andreas Thoma, Maja Zeller
STUDENTS PROTOTYPING	Stanislas Chaillou, Pierre Chevremont, Dzenis Dzihic, Maged Elsadek, Mathias Gfeller, Aniruddh Jain, Clemens Klein, Romain Kündig, Wai Loo, Thierry Raess, Andreas Thoma, Ramon Weber, Maja Zeller
SPONSORS	REHAU Vertriebs AG

DESCRIPTION

Depth Modulations project explored the robotic assembly of acoustically performative surfaces. Starting with strategies for robotically aggregating a generic, mass produced but highly articulated basic element, the students iterated designs through a digital production workflow utilizing industrial robotic arms. Their projects, developed through the production of scaled prototypes, enabled deeper evaluation and comparison of the different design implications and allowed the systematized control and manipulation of acoustic and aesthetic properties. The focus of the adjoining elective thesis workshop was deepening of the design concepts developed during the elective course and their implementation in 1:1 scale. Each of the four panel prototypes were composed out of 500 robotically cut and placed PVC tubes with a diameter of 70 mm which was determined according to the acoustic efficiency of the diffuse scattering of sound waves in the human voice range. To achieve the necessary air-tightness of the panels, the individual tubes were additionally internally sealed with individually positioned acrylic lids. The clearly noticeable influence of the prototypical panels on the room acoustics could then be successfully verified in the laboratory of Jürgen Strauss.

© Gramazio Kohler Research, ETH Zürich

REMOTE MATERIAL DEPOSITION

Centuries old ballistic methods enable and unexpected inversion of parameters. Instead of 3D printing with machines that enclose their fabricated pieces, an immobile machine can fabricate a structure many times larger than itself.

TYPE	Curving wall, robotic process with clay projectile shooting and deposition
MODE	Research and teaching project done at Gramazio Kohler Research, ETH Zürich
STATUS	Built
YEAR	2014
PLACE	Sitterwerk Kunstgieserei, St. Gallen, Switzerland
SIZE	10 m x 10 m x 1-2m
MATERIALS	Unfired clay shaped in cylindrical projectiles
SOFTWARE	Rhino, Python, Grasshopper
SETUP	Universal Robots UR5 on a custom spherical projectile rig
ROLE	Teaching lead
COLLABORATORS	Sebastian Ernst (research lead), Kathrin Dörfler, Sitterwerk Kunst und Produktion - Felix Lehner, Julia Lütolf, Ariane Roth, Laurin Schaub
STUDENTS INSTALLATION	Ralph Benker, Bo Cheng, Roberto Naboni, Pascal Ruckstuhl, Ivana Stiperski, Simone Stünzi, Anna Szabo, Andreas Thoma, Martin Thoma, Alexander Walzer, James Yeo
STUDENTS PROTOTYPING	Ayad Daniel, Maged Elsadek, Neel Jain, Orkun Kasap, Brenni Maria Seline, Yina Ng, Anna Szabo, Kosar Tayebani, Andreas Thoma, Maja Zeller
SPONSORS	Festo AG, Schweiz, Hans und Wilma Stutz Stiftung, Herisau, IKEA-Stiftung (Schweiz), Basel

DESCRIPTION

Remote Material Deposition explores the idea of robotically positioning material in space from a distance and thereby creating differentiated architectural aggregations that are a direct expression of a dynamic and adaptive fabrication process. As such, the elective course focused on the bi-directional link between digital and material processes, data and construction, and its integration within the architectural design. This approach was tested and validated through a series of scaled prototypical structures – not only broadening the tectonic spectrum but also asserting a specific architectural expression as a result of incorporating adaptive fabrication logic directly into the design process. In the elective thesis we continued our investigation into Remote Material Deposition and demonstrated – in cooperation with the Sitterwerk St.Gallen – this entirely new fabrication technique for the first time at full architectural scale. The architectural installation was a result of a one-month-long workshop and, within this scope, proposes a radically new way of thinking about materializing architecture. Featuring an industrial robot that aggregates material over distance and therefore exceeds its predefined workspace, this installation brings not only forward a novel scale of digital fabrication in architecture – it also takes a first step in characterizing a novel approach in digital fabrication, taking architecture beyond the creation of static forms to the design of dynamic material aggregation processes.

IRIDESCENCE PRINT

Although still rather slow, spatial thermoplastic extrusion is still one of the most economical 3D printing methods. It employs an efficient material distribution logic and paves the way to functional grading by engineering material properties through shape alone.

TYPE	Curving wall, robotic process with thermoplastic spatial extrusion
MODE	Research, teaching and an installation project done at Gramazio Kohler Research, ETH Zürich
STATUS	Built
YEAR	2015
PLACE	Palais de Tokyo, Paris, France
SIZE	8 m x 10 m x 1-2m
MATERIALS	ABS thermoplastic with pigments
SOFTWARE	Rhino, Python, Grasshopper
SETUP	Universal Robots UR5 on a 2-axis tower setup
ROLE	Teaching lead
COLLABORATORS	Andreas Thoma (installation lead), Norman Hack
STUDENTS INSTALLATION	Anna Szabo, Bo Cheng, Thijs van der Lely, Anne Cécile, Carfantan, Lex te Loo, Emma Flores Herrera, Nicolas Ganz, Pascal Ruckstuhl, Chen Ken, Altair Cerda Tirado
STUDENTS PROTOTYPING	Yu-Ting Sheng, Cerda Altair, Carfantan Anne- Cécile, Bo Cheng, Basile Diem, Emma Paola Flores, Chen Kaihong, Meloek Mlihi, Mirziyants Regina, Matteo Ricchi, Aike Steentoft, Anna Szabo, Lex te Loo, Ku Tsung-Hsun, Thijs van der Lely, Shih-Yuan Wang, Tristan Wicht
SPONSORS	Fondation Bettencourt Schueller

DESCRIPTION

In the elective course “Extruded Structures” the students explored the design potentials of robotically printed mesh structures. Initially starting with conventional triangulated space frame structures, they expanded their research towards combined multi-sided polygons like rectangles and hexagons, and developed custom printing sequences for non-standard spatial frames. These were fabricated as continuous extrusions at a scale of 1:10 using one Universal Robot UR5 robotic arm with a custom-built ABS filament extruder. Further differentiation strategies included three-dimensional grid extension, cantilevering, bridging and free-form supports. The findings were directly incorporated into the design and production of the installation Iridescence Print at the Palais de Tokyo in Paris. It is the first large-scale architectural installation to be automatically printed by robotic machines. Conceived as a spatially complex lightweight structure, the installation synthesizes a rigorous exploration of the architectural potentials of robotic extrusion of spatial meshes at full architectural scale. The multi-colored installation was developed during the elective thesis “Extruded Structures” and is exclusively presented at the exhibition „L’usage des formes – Artisans d’art et artistes” at the Palais de Tokyo, kindly supported by the Fondation Bettencourt Schueller.

© Kasia Jackowska

MAS DFAB PAVILION

What are the most basic parameters that distinguish a house from a pavilion? An elevated floor and multi-layered construction. Both of these are regularly skipped when dealing with digital fabrication applied to architectural scale.

TYPE	Pavilion with an upper floor and cladding, robotic process with integrated pre-fabrication and complex spatial assembly
MODE	Research and teaching project done at Gramazio Kohler Research, ETH Zürich
STATUS	Built
YEAR	2016
PLACE	ETH, Zürich, Switzerland
SIZE	8 m x 10 m x 6 m
MATERIALS	Wood beams connected with screws, wooden shingles as cladding
SOFTWARE	Rhino, Python, Grasshopper, Robot Studio
SETUP	2x ABB IRB 4600 on a common linear axis
ROLE	Teaching lead
COLLABORATORS	Philipp Eversmann (project lead), BLOCK Research Group, ETH Zürich, Chair of Sustainable Construction, ETH Zürich
STUDENTS INSTALLATION	James Chenault, Alessandro Dell'Endice, Matthias Helmreich, Nicholas Hoban, Jesús Medina Ibanez, Pietro Odaglia, Federico Salvalaio, Stavroula Tsafou
STUDENTS PROTOTYPING	James Chenault, Shiu Lun Cheung, Jorge Christie Remy-Maillet, José De Carvalho Paixao, Alessandro Dell'Endice, Larisa Gabor, Matthias Helmreich, Nicholas Hoban, Katrin Hochschuh, Wei Hsiao, Jesús Medina Ibanez, Ioannis Mirtsopoulos, Pietro Odaglia, Federico Salvalaio, Fabio Scotto, Stavroula Tsafou, Anastasia Zaytseva
SUPPORT	NCCR Digital Fabrication, funded by the Swiss National Science Foundation (SNSF)

DESCRIPTION

The Pavilion Project, developed by eight MAS students attending the one-year MAS DFAB programme, used digital methods and technologies to realize a unique two-story timber structure. Throughout the project, multiple prototypes were designed, fabricated, tested and refined, leading to a final project proposal. In order to fabricate the final proposal, a new robotic setup was developed and installed. In an automated process, the robot precisely pre-cut and assembled over 4,000 different elements into large component pieces which together created the walls, floors and enclosure. The final prefabricated elements are composed of three-dimensional spatial trusses autonomously clad with cedar shingles. The pavilion was then installed by assembling the individual prefabricated elements on-site. The project was realized in collaboration with Block Research Group (BRG) and the Chair of Sustainable Construction, both associated with the NCCR Digital Fabrication. The MAS programme is offered within the Department of Architecture at the ETH Zürich.

NAUTILUS CONSTRUCT

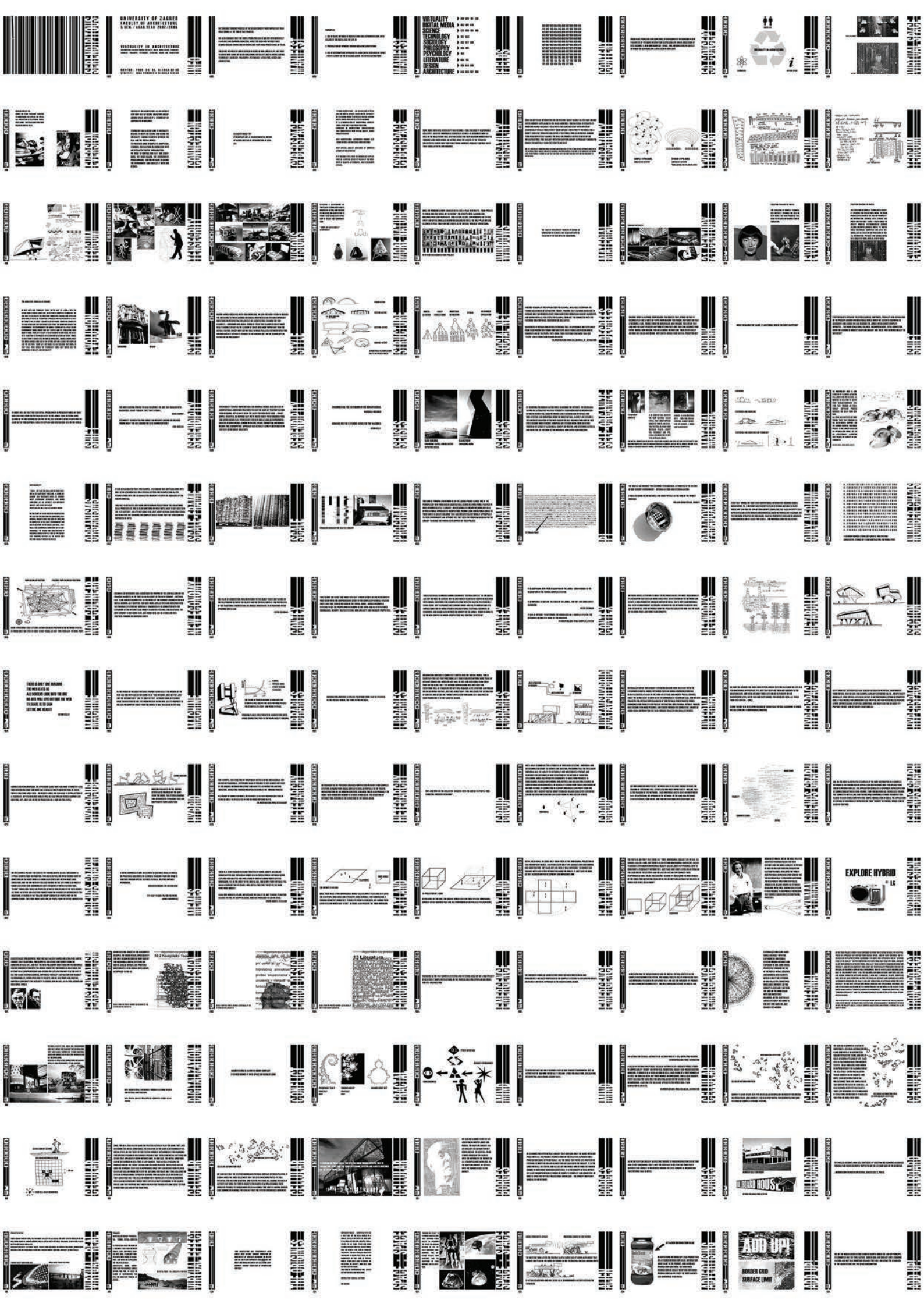
Nautilus has no client and no owner. It was initiated, conceived of and made by the people who built it as a gift to the city. Like its literary namesake, it belongs to everyone.

TYPE	Outdoor stage, manual production
MODE	Collective initiative by TEN Association, Zürich, and City Creative Network, Skopje
STATUS	Built
YEAR	2015
PLACE	Riverbank of Vardar, Skopje, Macedonia (FYROM)
SIZE	2 m x 20 m x 6m
MATERIALS	Painted steel profiles and treated fabric
ROLE	Co-Author
AUTHORS	Lukas Burkhart, Alexa den Hartog, Dejan Dinevski, Milan Dinevski, Damjan Kokalevski, Aurel Martin, Guillaume Othenin-Girard, Luka Piskorec, Nicolas Rothenbuehler, Karl Ruehle, Darko Krstevski, Yves Seiler, Nemanja Zimonjic
CO-AUTHORS	Sofija Bakalova, Jonatan Egli, Lucas Enzo Bucher, Iskra Filipova, Lukas Fink, Demjan Haller, Diandra Germann, Lukas Herzog, Ilcho Ilievski, Elena Jovanovska, Lazo Lazarov, Emilija Lelifanovska, Sandra Mojsova, Anne Marie Nagy, Monika Petrov, Micha Ringger, Martin Ristovski, Mirjam Schenk, Mihajlo Stojanovski, Jan Zurcher
COLLABORATORS	Ivana Angelova, Ana Boranieva, Elena Dinovska, Gligor Dubrovski, Erina Filipovska, Jasna Stefanovska, Milos Stokuca, Neven Kostic, Christian Gork
SUPPORT	Architectural Faculty of Skopje (AFS), Prince Claus fund for Culture and Development (PCF), City of Skopje, Ministry of Culture of Republic of Macedonia. GTA/ETH Zürich, Prof. Philip Ursprung, Skopje Fair, Balkans Arts and Culture Fund (BAC); as part of the project ACT4CITY

DESCRIPTION

Nautilus is a thoroughfare, a passage to the river, a place to sit alone and read, a playground for children, a platform for talks and readings, and a stage for performances, concerts, shows and happenings of various sizes. The structure is built to accommodate a singular user, or hundreds at a time. It invites appropriation by any group wishing to stage an event in the city of Skopje. Nautilus has no client and no owner. It was initiated, conceived of and made by the people who built it as a gift to the city, but it belongs to everyone. It is a collaborative work of young architects, artists, builders and craftsmen. The 20 meter long primary structure of Nautilus is constructed over and around the stone embankment wall, but does not touch it. It is built entirely out of steel and clad in strategic locations with a woven and painted textile developed especially for the project. The textile is used as a frame for the site, a projection surface and a delineator of different spaces of transition within the otherwise rigid repeated steel structure. On the riverside, it rises 6 meters above the bicycle path, presenting a tall screen to the water upon which images can be projected, but on the road side its height remains modest and unimposing, inviting discovery and inhabitation. Forming part of a knowledge exchange within the project, a group of 10 architecture students from Switzerland together with another 15 students from Skopje helped to realize and construct the structure in August 2015, in conjunction with the core project team.

SPECULATIVE


UNIVERSITY OF ZAGREB
FACULTY OF ARCHITECTURE
VIRTUALITY IN ARCHITECTURE
VIRTUALITY
DIGITAL MEDIA
SCIENCE
TECHNOLOGY
SOCIOLOGY
PHILOSOPHY
PSYCHOLOGY
LITERATURE
DESIGN
ARCHITECTURE
EXPLORE HYBRID
LG
ADD UP!
BORDER GRID
SURFACE LIMIT

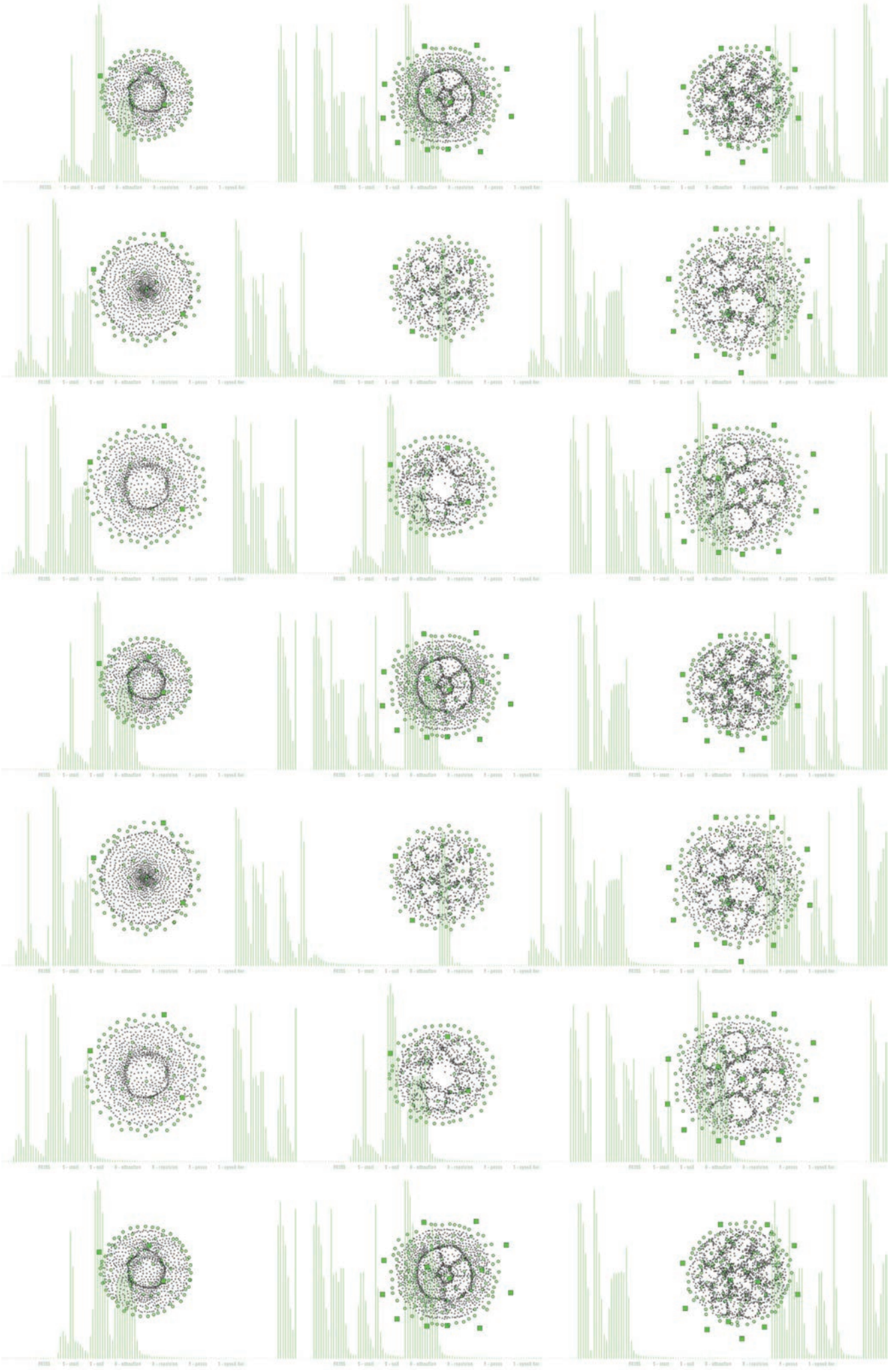
SERENDIPITOUS

Research methods focusing on resolving specific problems in a linear way were applicable in the Byronesque empirical paradigm, but they have to be revised with the regard to the digital age which is increasingly interconnected.

TYPE	Research booklet
MODE	Student project done at the Faculty of Architecture, University of Zagreb
STATUS	Completed
YEAR	2008
SIZE	130 pages
ROLE	Student
COLLABORATORS	Manuela Sedlar

DESCRIPTION

Research manifesto: We consider that the simple problems can be solved with generally available information and common knowledge, while the hard and difficult ones require obscure knowledge or knowledge from much wider range of fields. Therefore we presented our research in series of non-linear clips ranging from wide range of fields: digital media, science, technology, philosophy, psychology, literature, design and architecture. Principles used: 1. Use of basic methods of observation and experimentation, with regard to the digital age we live in 2. Provocation of opinions by breaking of conventions 3. Use of serendipitous approach to avoid linear research of topics - every element of the research can be the new starting point.



DISTRIBUTORIUM

By using methods borrowed from physics simulations, we can model Christopher Alexander's Pattern Nr. 2 as a standard equilibrium state system.

TYPE	Simulated model
MODE	Student project done at the Chair for Computer Aided Architectural Design, CAAD Theory – The Blind Architect, ETH Zürich
STATUS	Completed
YEAR	2009
SOFTWARE	Processing
ROLE	Student

DESCRIPTION

Christopher Alexander wrote about pattern language, which is in general a structured method of describing good design practices within a field of expertise. In his Pattern Nr. 2 he described the basic rules for the distribution of towns, expressed ultimately in given distances between different categories of towns and cities. By using dynamic methods, where each element is represented by a dynamically moving particle, each with its own attracting and repulsing forces, the problem becomes a standard equilibrium state system. Although approached at the beginning as a problem of spatial optimization by evolutionary algorithms, the foremost described method gave satisfactory results by an order of magnitudes quicker. Between the initial chaotic phase and the equilibrium state in the end, the system presented remarkable flashes of self-organizing patterns in the between-states, thus opening enough room for further investigations of such models.

© Damir Zizic

RE:PUBLIC

Oblique drawing as a method has a long and varied history, and especially in this age of digital and scale-less it is important to look at its potential in examining the city in all its layers and complexities.

TYPE	Publication and exhibition
MODE	Publication is based on the student workshop "Zagreb Rooms" held in the summer of 2014 and is published on the occasion of the Re:public exhibition in the French Pavilion
STATUS	Ongoing
YEAR	2015
PLACE	French Pavilion, Zagreb, Croatia
ROLE	Tutor and editor
EDITORS	Marija Blagojevic, Josip Jerkovic, Marta Lozo, Tamara Maric, Guillaume Othenin-Girard, Noelle Paulson, Luka Piskorec, Philip Shelley, Nemanja Zimonjic
TEXTS	Emma Jones, Ivan Himanen, Michael Hirschbichler, Paniz Musawi, Darko Separovic, Saca Simpraga, Alen Zunic
DRAWINGS	Irvin L Ahatovic, Irena Bakic, Eugen Canic, Nikola Kasic, Mia Kos, Roman Krajcarz, Marina Krcalic, Tamara Lukic, Matija Romic, Dora Sipina, Ivana Slavnic, Frane Stancic, Ivana Stancic, Mirna Udovcic
LAYOUT	Goran Jovanovic

DESCRIPTION

For Re:public, the city is the centre of attention. Its work calls for the renewal of the way we regard the city. Its name reflects the original derivation of republic - res publica - that which belongs to the people, the public realm, our common ground. In the summer of 2014 Re:public held a week-long drawing exercise in Zagreb as part of an on-going programme of teaching and research. This exhibition and its catalogue bring together a selection of the drawings set in a wider cultural context: seven drawings, each paired with a text and an art reference associated with the subject it depicts. Together, they create a space in which they can be considered alongside one another for the first time. In the drawing exercise, the representational technique they chose to employ was the oblique drawing, a mode of drawing with a long and varied history. Each drawing, made by pairs of students, used the cadastral map for its basis. Thus, the exact geometry and relations between the elements were preserved while the drawings were given a vertical dimension. Why embark on such a project? A greater literacy of urban form would improve the quality of the discourse surrounding the city - an antidote to present object-oriented and solution-based fixations - glossy images of buildings serving the desires of everyone apart from the public itself.

HAUS OHNE EIGENSCHAFTEN

The interactive piece was intended to spark the critical thinking about the vocabulary used in architecture by, paradoxically, generating grammatically valid but meaningless "reviews" of residential houses.

TYPE	Exhibition
MODE	Interactive piece done for Architektur 0.15 exhibition by the Walter Steiner Kollektiv
STATUS	Finished
YEAR	2015
PLACE	Maaghalle, Zürich, Switzerland
ROLE	Co-Author
COLLABORATORS	Walter Steiner Kollektiv

DESCRIPTION

The newly built environment in Switzerland reflects the vocabulary through which it is communicated. That is a vocabulary which makes itself independent in today's architectural discourse and which, unquestioned, represents our ideals and standards. It contains words which have only positive connotations and are used as complements, although they contradict each other in their true meaning. Without raised questions, they are stretchy, versatile and seem to rather be a reflection of morality and values of its user than it's confrontation with architecture. Through their use, these words are completely stripped of their importance and became degenerated platitudes and projections for diffuse hopes. This autonomized, adaptive vocabulary simultaneously sets the directives in the development process of architecture. In this way, it becomes the reasoning basis for dialogue in the Swiss culture of consensus. In the tension between architects, planners, private investors and the public sector this consensus manifests itself as agreement and approval, where dissent and diversity are perceived as disruptive, which is consistent with a lack of resistance. The built consequence of this consensus is an architecture of compromise - because while none of the parties revolts on the way to this agreement, the cutbacks fall back solely on the architecture. The enfeebled idea loses all ability to make its statement, critical question or a political attitude clear and understandable. The final product and its compatibility stand over its content and the fear of the unknown triumphs over curiosity. Extra effort would have to be demanded from architects for courage, ingenuity and criticism, in order to oppose the absurdity and arbitrariness in the process of making architecture, dried up under the pressure of the economy, the dependency on the inter-disciplinary circus, the social norm and his own self-centered pursuit of success. If architecture becomes pure fulfilment of requirements, rooted in an unreflected, undifferentiated vocabulary, without possessing a coherent whole, then the compromise becomes the enemy of every idea. We must obtain a precise vocabulary to discuss architecture in a critical way.

NOTES FROM THE BOOK OF SAND

"The small illustrations, I verified, came two thousand pages apart. I set about listing them alphabetically in a notebook, which I was not long in filling up. Never once was an illustration repeated." Jorge Luis Borges – "El libro de arena", 1975

TYPE	Blog
MODE	Digital documentation of personal notebooks
STATUS	Ongoing
WEB	http://notesfromthebookofsand.tumblr.com/
YEAR	2006-
SIZE	3000+ pages
ROLE	Author

DESCRIPTION

Notes from the Book of Sand refers to a short fantastic story written by an Argentinian author Jorge Luis Borges. He imagined a book with infinite amount of pages where every page would contain meaningful content (as opposed to the books in his "The Library of Babel") and the sheet itself could always be split in two ad infinitum. The main character, Borges himself, even starts listing all the illustrations found in the book in a separate notebook, a futile task. This story was a direct inspiration for the method of digitalizing and publishing personal notes made since 2006 on a public blog. Any attempt to further catalogue or edit them proved to be futile, but the project, itself a pure "graphical content", opens some interesting venues for the future. Interestingly, as opposed to his other fantastic stories written as false testimonies, this is the only one Borges claimed to actually be true, and that he hid the book in La Biblioteca Nacional in Buenos Aires, an institution of which he was a long time director.

THESES

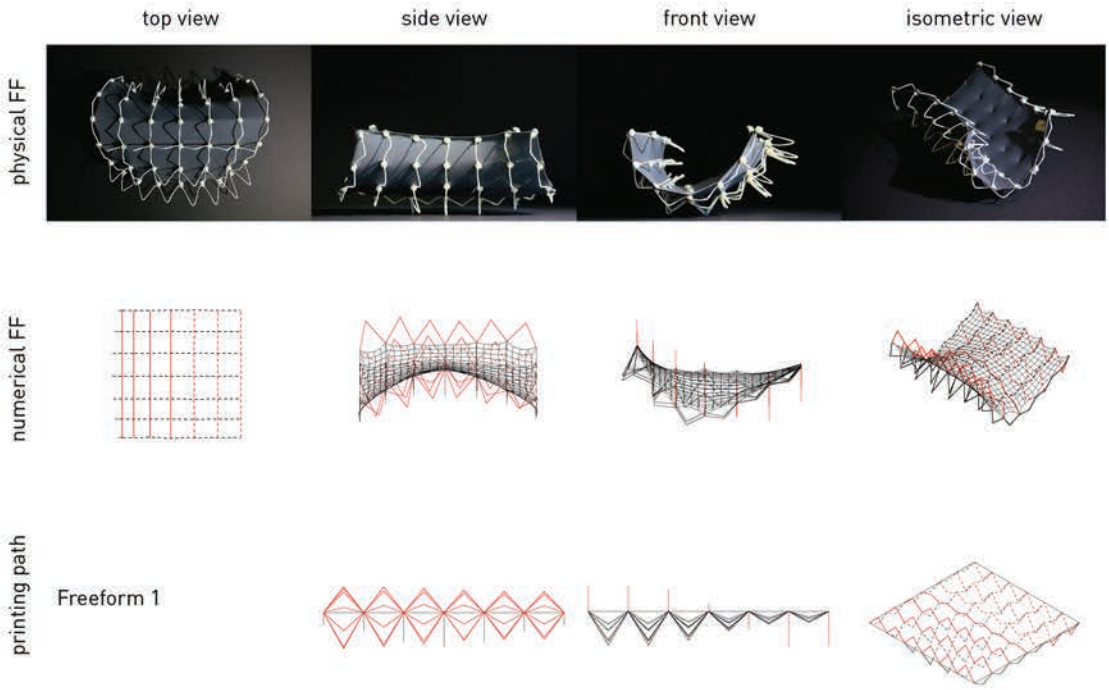


Fig. 45. Freeform 1, samples comparison.

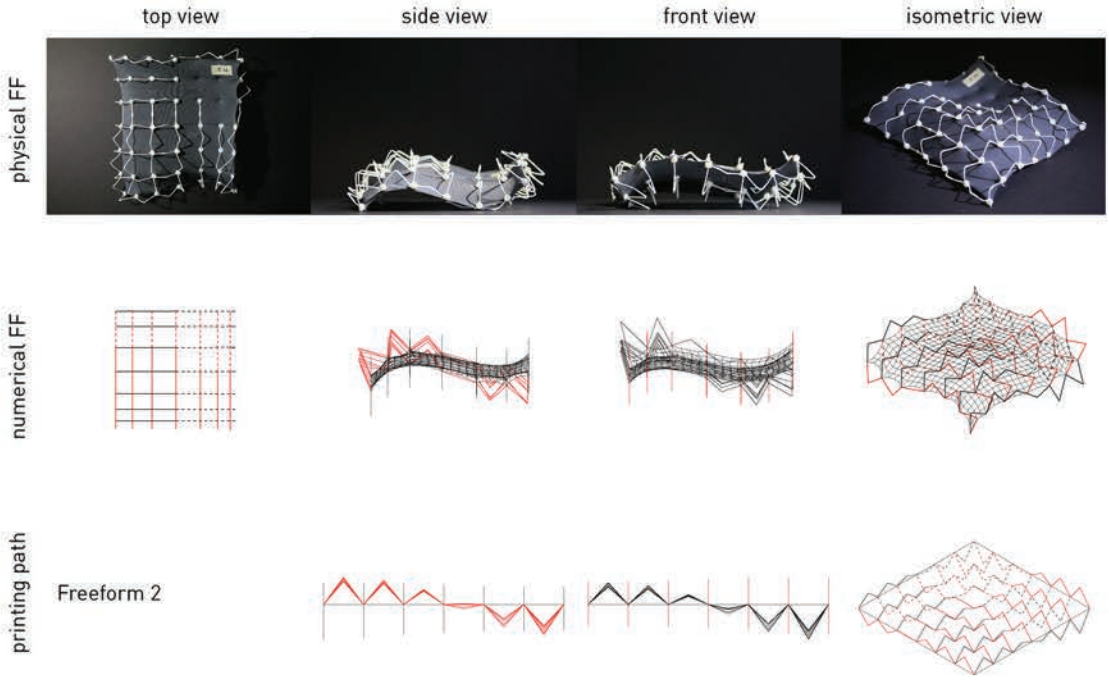


Fig. 46. Freeform 2, samples comparison.

SPATIAL TEXTILE HYBRIDS: SELF FORMING 3D-PRINTING-INDUCED STRUCTURES

4D printing enables us to fabricate artefacts in compact configurations, while the "programmed" material behavior embedded during the process enables the artefact to unfold in its final shape after the fabrication is done.

TYPE	Master thesis
MODE	Master thesis submitted for Master of Advanced Studies in Architecture and Digital Fabrication, ETH Zürich
STATUS	Submitted
YEAR	2016
PLACE	ETH, Zürich, Switzerland
SIZE	30 cm x 30 cm x 10 cm
MATERIALS	ABS thermoplastic, nylon
SOFTWARE	Rhino, Python, Grasshopper
SETUP	Universal Robots UR5
ROLE	Mentor
THESIS ADVISORS	Prof. Fabio Gramazio, prof. Matthias Kohler
STUDENT	Jorge Christie

DESCRIPTION

This thesis presents a novel approach for generating textile hybrid structures based on the actuation of a pre-stressed fabric with in-space robotic 3D printing. The so-called Spatial Textile Hybrids are introduced starting with its initial material explorations and physical form finding, from where a behavioral logic is deduced and relevant data extracted concerning the generation of parametric models of the system. Thereafter, a preliminary computational design framework is proposed as a set of tools ranging from printing path prediction to form finding and printing path design. In order to test the system's transformation hypothesis and, later, to illustrate the potential of this approach for designers, a constant feedback loop from physical prototyping and computational design was investigated.

Once the vault was half completed, the wooden base was moved backwards, further from the robot, which was a twofold decision: (a) helped to avoid robot collision with either itself or the built vault and (b) proved that this technique can be transferred to a railed robot which in theory could continue fabrication infinitely, replicating the same corrugation pattern.

The final result, as well as photos during the fabrication, are shown below:

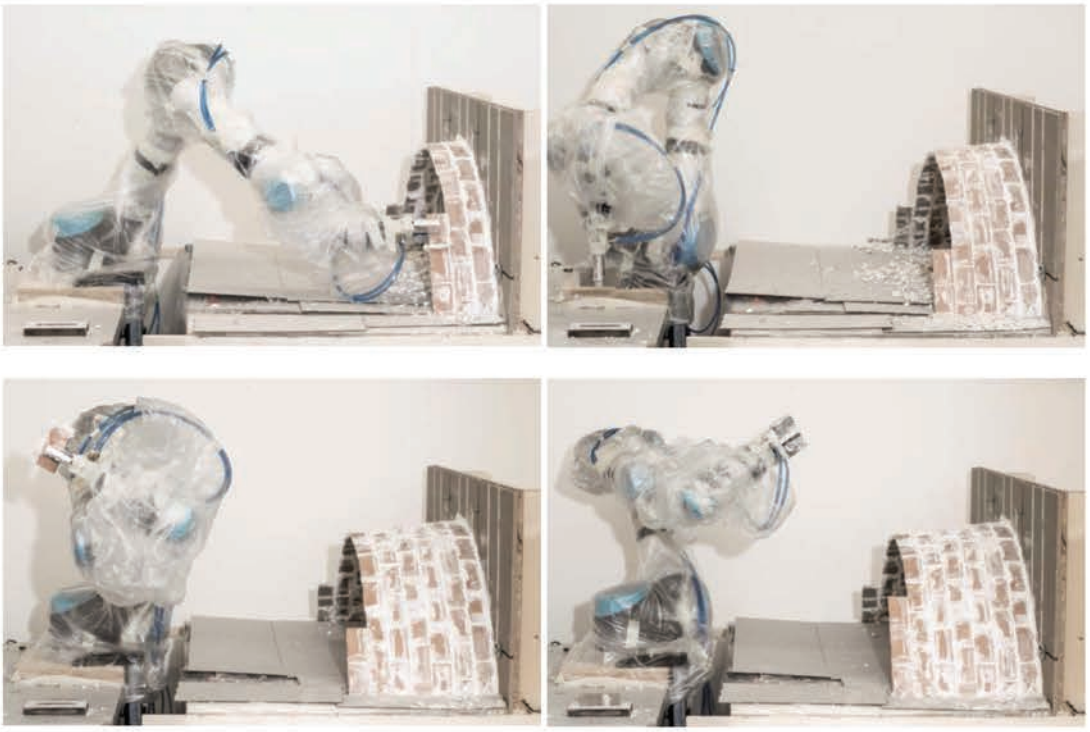
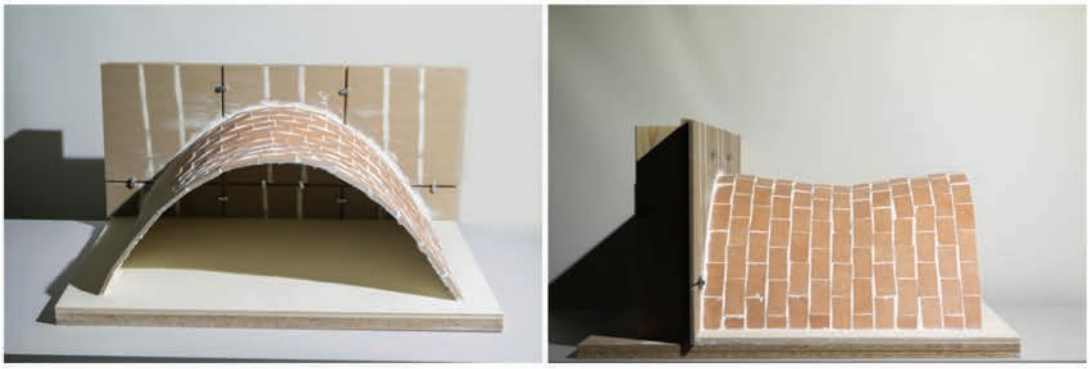


Fig.39: snapshots during fabrication



ROBOTIC FABRICATION OF CATALAN VAULTING: CONTROLLING FEASIBILITY THROUGH CURVATURE MANIPULATION

Catalan vaults are one of the finest examples of traditional craftsmanship. Built without formwork, they depend on precise guide-work to attain the optimal shape. By using robotic placement and its absolute precision, the potential repertoire of shapes for Catalan vaults can be greatly expanded.

TYPE	Master thesis
MODE	Master thesis submitted for Master of Advanced Studies in Architecture and Digital Fabrication, ETH Zürich
STATUS	Submitted
YEAR	2016
PLACE	ETH, Zürich, Switzerland
SIZE	40 cm x 60 cm x 40 cm
MATERIALS	Ceramic tiles, Plaster of Paris
SOFTWARE	Rhino, Python, Grasshopper
SETUP	Universal Robots UR5
ROLE	Mentor
THESIS ADVISORS	Prof. Fabio Gramazio, prof. Matthias Kohler
ASSISTANCE	Dr. Matthias Rippmann, David López López
STUDENT	Ioannis Mirtsopoulos

DESCRIPTION

This thesis presents a semi-automated, with limited human interaction, robotic fabrication system for the construction of Catalan vaults, with absence of formwork, implemented for the scale of prototyping and thus using portable robotic arms. Simple computational tools have been developed to explore the relation between the tiling and fabrication of compression-only vaults. Form finding of vaults has been made with Thrust Network Analysis (TNA), implemented through RhinoVAULT of Block Research Group (BRG), taking into account physical model investigations on the tiling adhesion and the workable curvature of the used plaster and tiles. Robotic paths were generated for the pick-and-place process, whereas the application of plaster on the tiles' sides was done manually. This thesis also presents a series of documented built models towards the direction of a robotically fabricated Catalan vault.

etc [Fig. 18]. The design variations from the system are already being informed with these necessary information as early as when they are being designed.

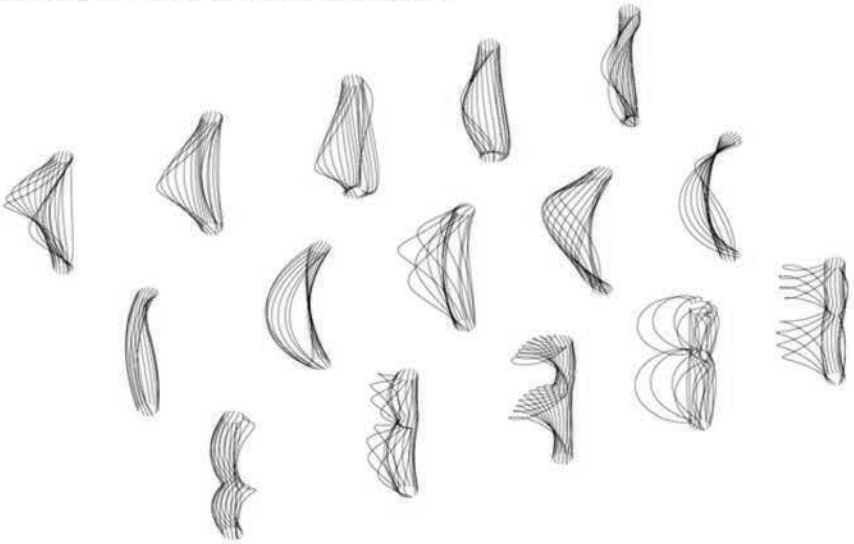


Fig. 17 Display of prototypes based on the integrated generative design system

There is also a great freedom on the arrangements of the bounding conditions [Fig.19]. We could create vertical set of planes arranged in the form of a circle. This design strategy would utilize a larger range of the robot reach. The curvature of the extrusion path is deeply related to the robot's base location, limbs' lengths and transition choices. These seemingly technical information also have a role in forming the uniqueness of the design form.

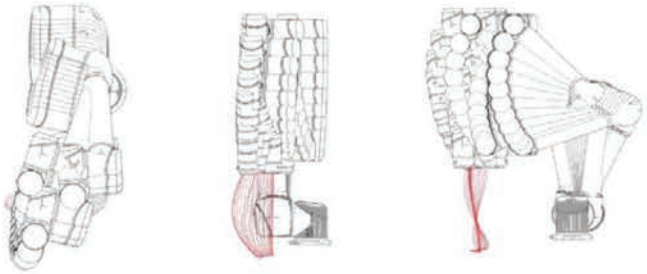


Fig. 18 Relation of form and the continuous robotic movement

Fig. 19 Relation of form and the continuous robotic movement utilizing Axis 1 of UR robot

THE VITRUVIAN ROBOT: INTEGRATED ANALOGUE AND DIGITAL PARAMETERS FOR DESIGN AND FABRICATION OF SPATIAL TUBULAR EXTRUSION

Forward and inverse kinematic equations have been employed since the onset of robotics, but the potential of kinematic movement itself and its spatial trajectories is not thoroughly explored in the context of digital fabrication.

TYPE	Master thesis
MODE	Master thesis submitted for Master of Advanced Studies in Architecture and Digital Fabrication, ETH Zürich
STATUS	Submitted
YEAR	2016
PLACE	ETH, Zürich, Switzerland
SIZE	50 cm x 50 cm x 20 cm
MATERIALS	PVC pipes
SOFTWARE	Rhino, Python, Grasshopper
SETUP	Universal Robots UR5
ROLE	Mentor
THESIS ADVISORS	Prof. Fabio Gramazio, prof. Matthias Kohler
STUDENT	Shiu Lun Cheung, Kenneth

DESCRIPTION

This thesis presents a method for integrated design using robotic kinematics constraints in large scale 3D spatial printing with tube filaments. The main discussion in the paper would focus on the continuous movement of the robot instead of “pick and place” discrete movements. The method is developed as a research thesis of the Master of Advanced Studies ETH in Architecture and Digital Fabrication. It entails the extraction of inverse kinematics in robotics combined with spatial bounding conditions to design planned continuous movement for scalable tube filament printing. Hereby a direct connection is built between axis incremental control and spatial form, in which spatial bounding conditions are not the only parameters, but also the articulation of axis transition takes part in the design of the 3D object. Moreover, end effector has been developed as a demonstration of the printing process by softening tubular filament in a controlled environment. The concept of integrating spatial design conditions with the articulation of embedded axis transition is aiming at pulling down the separation between design parameters and physical robotic movement constraints by introducing axis transition as one of the design driven variable.

5.3 Bending Station Experiment_

There are three bending station that test at first to see which is the most effcient and proper method could be achieve.

_5.3.1 Vision_1 - Rotating Bending Station

The first test station is rotating bending station, the robot grip the tube to rotate in certain angle and using gravity to deform the glass tube.

Problem: 1.Only can bend in 90 degree angle.
2.Different section require different timing for bending.

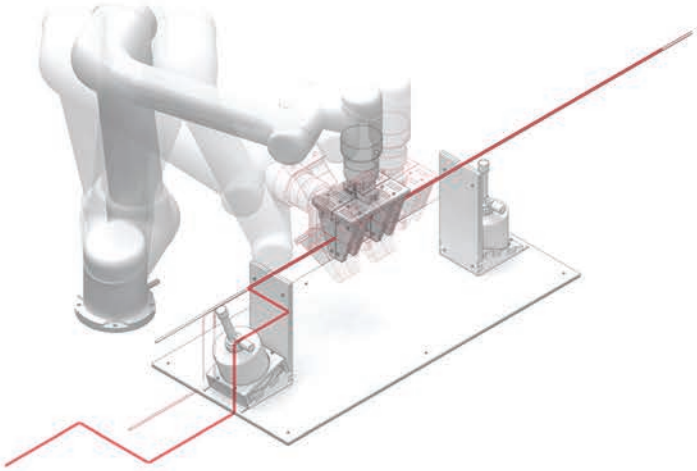


Fig. 10. Rotating Bending Station Process

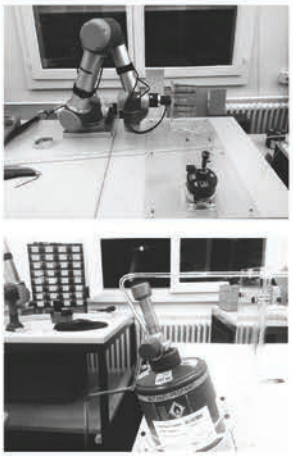


Fig. 10.1. Rotating bending experiment

_5.3.2 Vision_2 - Angle Bending Station

The second test station is angle bending station, using robot's 6 axis feature in space, attaching to the torch that allow gravity to deform the bending angles.

Problem: 1.Centrifugal pendulum.
2.Difficult to shift next secotr to bend.

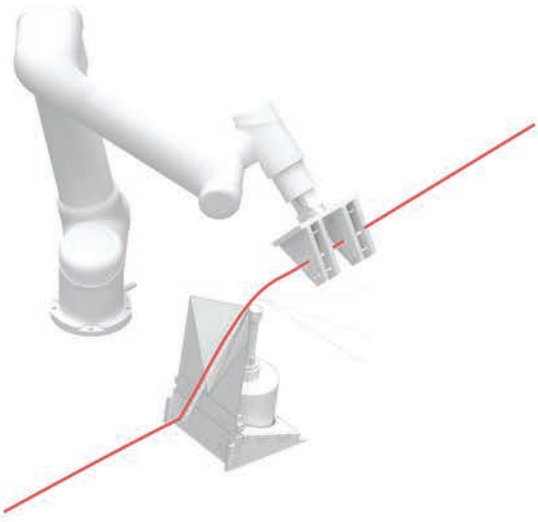


Fig. 11. Angle Bending Station Process

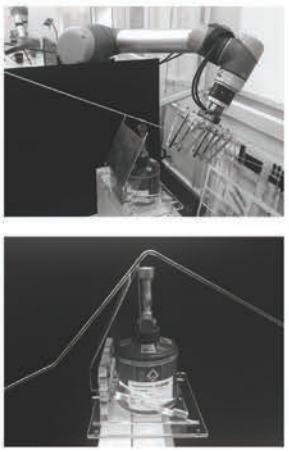


Fig. 11.1. Angle bending experiment

ROBOTIC SPATIAL BENDING OF GLASS RODS

Glass is an extremely difficult material to process in a differentiated way. Precise control of material temperature, its distribution during the formation process and timing are crucial for controllable results.

TYPE	Master thesis
MODE	Master thesis submitted for Master of Advanced Studies in Architecture and Digital Fabrication, ETH Zürich
STATUS	Submitted
YEAR	2016
PLACE	ETH, Zürich, Switzerland
SIZE	50 cm x 50 cm x 3 m
MATERIALS	Glass rods and pipes
SOFTWARE	Rhino, Python, Grasshopper
SETUP	Universal Robots UR5
ROLE	Mentor
THESIS ADVISORS	Prof. Fabio Gramazio, prof. Matthias Kohler
STUDENT	Wei-Yu Hsiao, Ronald

DESCRIPTION

The objective of this research project is to investigate and develop techniques and methodologies for robotic spatial glass bending that allows for the efficient production of geometrically complex glass tubes. The developed bending technique is performed by the six-axis industrial robot arm which bends glass tubes in a series of precise angles. Contrary to traditional manual glass bending process, this procedure facilitates more efficient and differentiated fabrication. The aim is to further the development of advanced glass bending fabrication methods and corresponding simulation processes, which can potentially be transferred to other materials and fabrication at large scales.

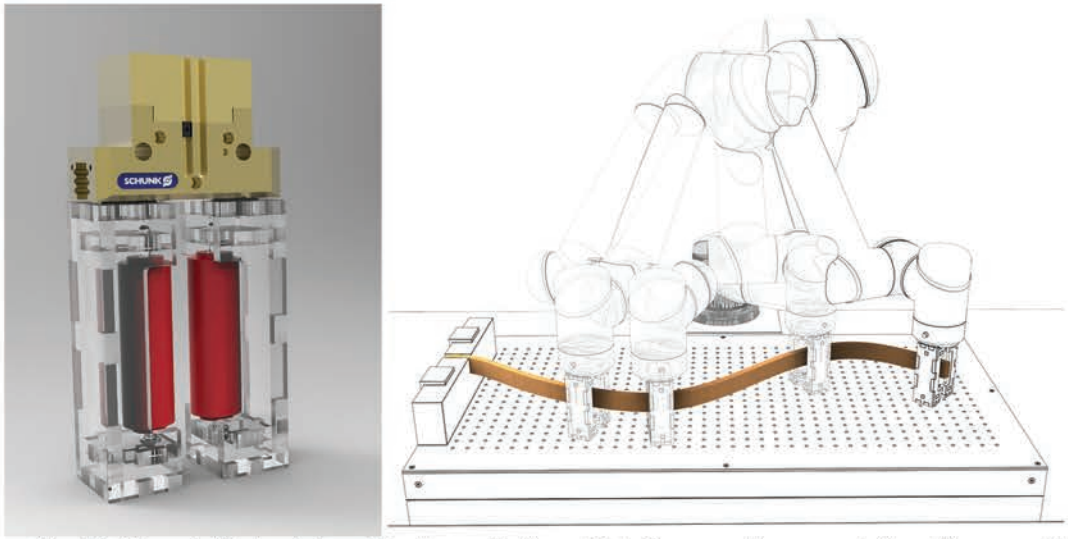


Fig. 11 *left:* end-effector designed for the application; *right:* diagrammatic representation of incremental bending;

To address this problem, the focus was addressed to the role of the glue in the bending process. Although different adhesives have been tested, the uniformity of the bonding time of the glue, did not favour alone the possibility of sequential bending. Further analysis, led to the assumption the bending process could benefit from the integration of mechanical fasteners that could restrain the spring-back forces acting on the bent veneers while allowing the chemical adhesion of the glue to take place.

Tests were made by introducing clips and wood staples as methods for fixing the veneers strips while bending was applied. The first didn't provide adequate strength in opposing the bending strains from pushing the material back to its initial pre-bent shape. The staples also didn't produce any satisfactory results and, in addition, their application proved to be highly disruptive for the thin veneer strips.

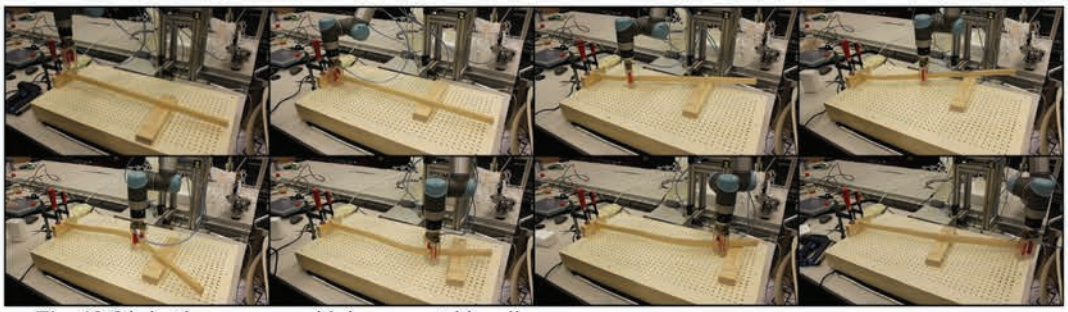


Fig. 12 fabrication process with incremental bending

The analysis of those factors progressed to the conclusion that incremental bending could not be implemented with robotic fabrication without replacing the fundamental functionality the wooden dowels had in the manual fabrication tests. The methodology of bending was then further reviewed and its execution readjusted to accommodate the requirements of the redefined procedure.

ROBOTIC ELASTIC BENDING OF GLUE LAMINATED WOOD VENEER

The aim was to develop an integrative process able to closely reproduce an input digital geometry representing deformable veneer elements and to fabricate it as a physical artefact.

TYPE	Master thesis
MODE	Master thesis submitted for Master of Advanced Studies in Architecture and Digital Fabrication, ETH Zürich
STATUS	Submitted
YEAR	2016
PLACE	ETH, Zürich, Switzerland
SIZE	1.6 m x 1.6 m x 40 cm
MATERIALS	Glue laminated wood veneer
SOFTWARE	Rhino, Python, Grasshopper
SETUP	Universal Robots UR5
ROLE	Mentor
THESIS ADVISORS	Prof. Fabio Gramazio, prof. Matthias Kohler
STUDENT	Fabio Scotto

DESCRIPTION

The project focus on the understanding of the elastic capabilities of wood veneers and applies it to robotic fabrication for the realization of glue laminated bent elements. Although the latest digital simulation engines offers great visual representation of material performances, their application to digital fabrication methods generally creates unsatisfactory results in predicting and evaluating material behaviors. In this research, particular attention is given to the possibility of bridging a computational design scheme to a precise robotic fabrication procedure with the aim of delivering an integrative process able to closely reproduce an input digital geometry to a realized physical product.

6.3 Algorithm Experiments

After defining the different data sets for the prediction models, it is necessary to fine-tune the hyperparameters of the learning function in such a way that it is neither generalizing the data too smoothly nor overfitting it, which is both leading to bad prediction results.

By initially inputting the training data (for any of the three prediction data sets) it is shown that the data is much denser in certain areas of the function. For showing the different influences of hyperparameters and the correlation to the input data, the graphs at zero height are compared in the following, as they hit the highest number of data points.

The areas, where no data points are collected, are assumedly the areas of the graph that should produce bad printing results and high deviations. As the input data points are also including deviations, the mean of the function was moved up to compensate for the lack of information in those areas, where by experience a high deviation is presumed.

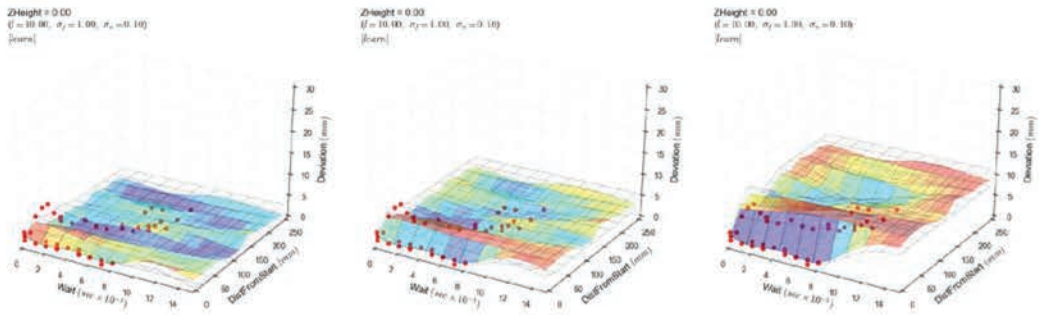


Fig. 15. Impact of varying mean μ (0.0, +5.0, +15.0) on the same GP function

The hyperparameter of the length scale is changing the wavelength of the function, while sigma f is the covariance amplitude and sigma n is the observation noise. Different combinations of those settings have been graphically produced and led to a decision to choose two different hyperparameter settings to test for the actual prediction and 3D-printing.

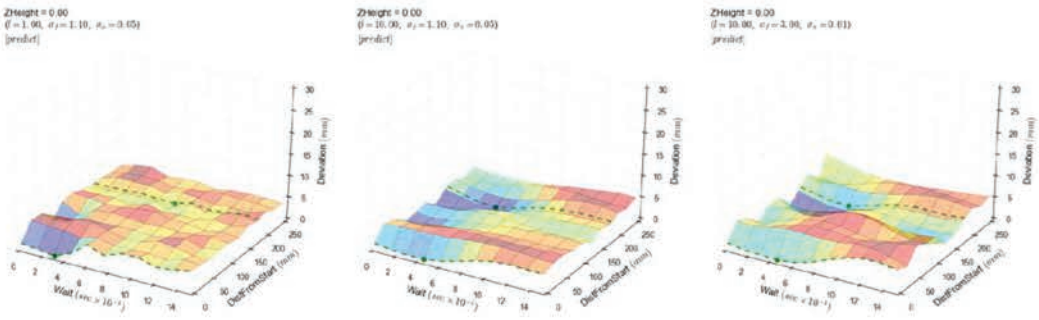


Fig. 16. Impact of varying hyperparameters (length l, covariance amplitude σ_f and observation noise σ_n) on the same GP function

AUTONOMOUS 3D PRINTING OF SPATIALLY EXTRUDED STRUCTURES THROUGH MACHINE LEARNING

Although machine learning depends heavily on the large amount of gathered data representing system parameters, methods exist that can use even small number of iterations to create useful predictive models, which can in turn be used to optimize complex fabrication tasks.

TYPE	Master thesis
MODE	Master thesis submitted for Master of Advanced Studies in Architecture and Digital Fabrication, ETH Zürich
STATUS	Submitted
YEAR	2016
PLACE	ETH, Zürich, Switzerland
SIZE	4 cm x 10 cm x 1-10 cm
MATERIALS	ABS thermoplastic
SOFTWARE	Rhino, Python, Grasshopper
SETUP	Universal Robots UR5
ROLE	Mentor
THESIS ADVISORS	Prof. Fabio Gramazio, prof. Matthias Kohler
STUDENTS	Katrin Hochschuh, Jose Paixao

DESCRIPTION

The 3D printing of spatially extruded structures with a 6-axis robot offers the architectural context to explore another highly technological field - the one of machine learning. Seeing the potential of not only using the machine as an executor of clearly defined commands, but also as a system that is incorporating an intelligence based on experience, a completely new attempt to architecture and material logics can be thought. At the interface between digital and physical, this project explores the potentials and limitations of designing the solution to the problem of imprecision of material deposition during a 3D extrusion process by machine learning. The results demonstrate the varying performance of different prediction models and the significance of the feature extraction logic, quality of data and setup as well as algorithm settings for the success of the solution.

Room temperature

T > 30 °C

T > 40 °C

5.2.2 Temperature responsive bilayer material: Carbon fiber and PVC

As a consequence of the first experiment, the second one was done in order to increase the response, either in the bending percentage, or on the temperature scale, actuation starting at a lower temperature. This experiment and the material choice was done by us. The choice of materials came out of the reason that carbon fibre has the lowest thermal expansion coefficient, whereas polymers, the highest (see fig. 6.). Hypothetically a combination of extremes should lead to the best response. Moreover, carbon fibre is responsive to radiation, heating up quickly when exposed to sun light, making the bilayer react at a lower temperature than in previous case.

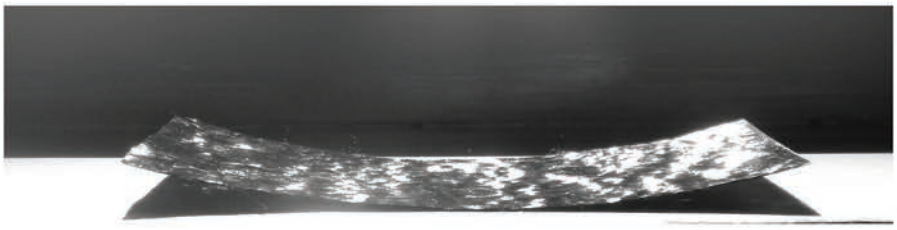


Fig. 9. Carbon fiber and Polymer composite exposed to radiation and T > 25 °C

The exposure of the composite at outdoor conditions for several days revealed that the material it is changing its behaviour over time, probably due to humidity factors. It is still maintaining its responsive properties, bending at different rages of temperature, but its shape shift doesn't remain constant. If the material was flat at the lamination temperature, convex at a higher, and concave at a lower temperature, over time this parameters can change. This behaviour was not noticed in the previous experiment, and this observations led to our third experiment.

ADAPTIVE BUILDING SKIN

Integration of new composite materials and already established 3D printing methods can enable the production of "smart" building envelopes with graded properties adaptable to the actual environmental conditions.

TYPE	Master thesis
MODE	Master thesis submitted for Master of Advanced Studies in Architecture and Digital Fabrication, ETH Zürich
STATUS	Submitted
YEAR	2016
PLACE	ETH, Zürich, Switzerland
SIZE	30 cm x 20 cm x 10 cm
MATERIALS	Transparent PLA thermoplastic
SOFTWARE	Rhino, Python, Grasshopper
SETUP	Universal Robots UR5
ROLE	Mentor
THESIS ADVISORS	Prof. Fabio Gramazio, prof. Matthias Kohler
STUDENTS	Larisa Gabor, Anastasia Zaytseva

DESCRIPTION

This thesis articulates a conceptual paradigm for the development of high-performance building envelopes that are adaptive and responsive to environment. Based on a set of morphogenetic techniques, using as biological model - the skin tissue, an assembly of a heat-radiation actuated smart membrane and a porous wall, a composite combining real-time environmental response and thermal performance, alternating ventilation and insulation properties, is being rationalized, deploying computational design and digital fabrication methods.